DUST PALLIATIVE MEAN PARTICLE RESIDENCE TIME CALCULATOR

FINAL PROJECT REPORT

by

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for

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In cooperation with U.S. Department of Transportation,
Research and Innovative Technology Administration (RITA)

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

DUST PALLIATIVE MEAN PARTICLE RESIDENCE TIME CALCULATOR

5. Report Date

4 Jan 2021

6. Performing Organization Code

7. Author(s) and Affiliations

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8. Performing Organization Report No.

9. Performing Organization Name and Address

Center for Safety Equity in Transportation
ELIF Building Room 240, 1760 Tanana Drive
Fairbanks, AK 99775-5910

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address

United States Department of Transportation
Research and Innovative Technology Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

13. Type of Report and Period Covered

Final

14. Sponsoring Agency Code

15. Supplementary Notes

Report uploaded to:

16. Abstract

Previous research efforts at UAF have established that dust palliative performance may be compared using a calculation called the mean particle residence time ⍰ (tau, or MPRT). The MPRT value is computed using linear regression techniques to determine the time when the dust palliative loses its effectiveness. A technician tests the palliative using a dustfall column and a nephelometer to measure the concentration of PM10 over time. The technician needs to manually process this raw data with an Excel spreadsheet making dust palliative MPRT reports time-consuming and prone to error. Finally, the certifying technician prints and files the report for future reference which limits future dissemination. We developed a web-based calculator, called UAFDUST, to automate the process of producing the MPRT report. UAFDUST combines a web app front end using Google's Angular library with a PHP and SQL database backend. This database enables a laboratory to record metadata about the dust palliative including the dustfall column testing date and technician, certification date, and certifying technician. The app calculates the MPRT and produces accompanying linear regression plots. The UAFDUST app stores dust palliative MPRT tests in a public database and trained laboratory technicians may contribute new data.

17. Key Words

Dust Control, Rural Transportation, Statistical Analysis, Quality of Specific Environments

18. Distribution Statement

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	25	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

Previous research efforts at UAF have established that dust palliative performance may be compared using a calculation called the mean particle residence time τ (tau, or MPRT). The MPRT value is computed using linear regression techniques to determine the time when the dust palliative loses its effectiveness. A technician tests the palliative using a dustfall column and a nephelometer to measure the concentration of PM_{10} over time. The technician needs to manually process this raw data with an Excel spreadsheet making dust palliative MPRT reports time-consuming and prone to error. Finally, the certifying technician prints and files the report for future reference which limits future dissemination. We developed a web-based calculator, called UAFDUST, to automate the process of producing the MPRT report. UAFDUST combines a web app front end using Google's Angular library with a PHP and SQL database backend. This database enables a laboratory to record metadata about the dust palliative including the dustfall column testing date and technician, certification date, and certifying technician. The app calculates the MPRT and produces accompanying linear regression plots. The UAFDUST app stores dust palliative MPRT tests in a public database and trained laboratory technicians may contribute new data.

CHAPTER 1. INTRODUCTION

1.1. Overview

Previous research efforts at University of Alaska Fairbanks (UAF) have established that dust palliative performance may be compared using a calculation called the mean particle residence time τ (MPRT) [Bar18]. This calculation currently uses an Excel spreadsheet and manual processing of raw data. This makes sharing dust palliative MPRT reports time consuming and prone to error. We proposed to develop a cloud-based calculator to automate this process to automatically generate the report and share with Alaska Department of Transportation personnel to support continued research with comparative dust palliative studies.

Our main result is that we have developed a system called UAFDUST which is capable of automatic analysis and reporting of dust palliative mean particle residence time tests via a front-end website and back end database. The system can import raw text data and output an interactive report which a technician can use in their preparation of a formal report. We identified the following requirements for this process:

- Use a database to store and retrieve reports
- Enable printing to a PDF for filing
- Accessibility on the world wide web
- Record test and lab certification dates
- Record testing and certifying technicians
- Record textual metadata
- Record machine readable raw test data

In the following chapters we will discuss how we provided a solution for each of these requirements. The outline of this work includes a literature review, an overview of the kinds of data that need to be processed, the UAFDUST system architecture, our findings, and finally conclusions. The appendices include minutes from the expert task group and the technology transfer plan.

1.2. Previous Work

In previous research, University of Alaska's Institute of Northern Engineering (INE) (Barnes, 2018; Connor, 2017) worked on the problem of understanding dust management in rural areas. Dirt roads are common in rural areas and during the summer months in Alaska can result in poor air quality when vehicles kick up dirt into the air. Palliatives can be used to control dust by coating the road with a substance that can keep the smaller particles, which take longer to settle than rocks, from getting into the air. Many kinds of palliatives have been identified for usage in a variety of applications and we refer the reader to a guide (Rushing & Tingle, 2006). Regardless the chemical composition, which may be a custom formulation from a company or laboratory, it is important to verify whether they are effective. The dustfall column test (Barnes, 2018) is one such test, and it is fed into a mathematical algorithm to determine the Mean Particle Residence Time (MPRT). Trained technicians can use the MPRT to make direct comparisons between different palliatives. This is the basis for this work which is to automate the calculation and enable a laboratory to maintain a database of palliatives.

CHAPTER 2. DATA AND METHODS

2.1. Dustfall Data Collection

The data for use in the UAFDUST application comes from a combination of a dust- fall column and an aerosol sensor. We used a TSI Dusttrak II sensor (TSI Incorporated, 2020). Figure 2-1-1 shows the dustfall column and the aerosol sensor. The source data is raw text recorded by the dust sensor as the dust falls inside the dustfall chamber. Sample data are shown in Appendix A. We get two columns of information. The first column is the time measured in seconds and the second column is the concentration C measured in mg/m^3. For this document, we will use the sample data as the source for example graphs and calculations. Figure 2-2 shows a plot of the sample data from Appendix A.

Figure 2-1. The dustfall column and the aerosol sensor used to record data for the UAFDUST application.

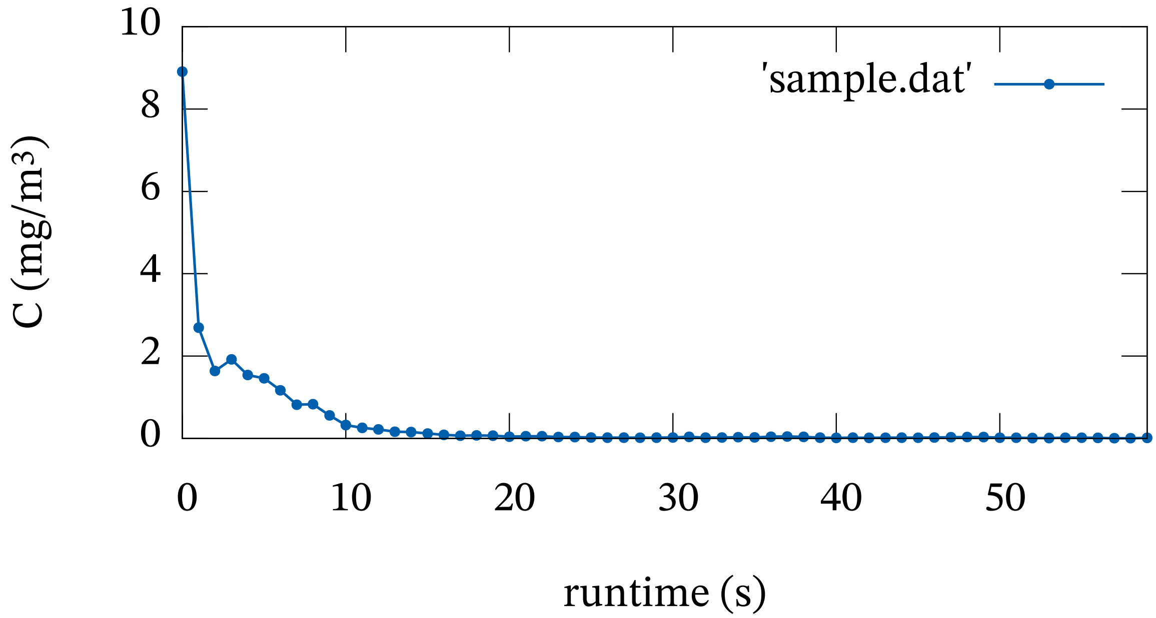

Figure 2-2. Plot C(t) of data from Appendix A.

2.2. Mathematical Analysis

To calculate the *mean particle residence time*, we need to apply some statistical calculations. We use the following equations:

$$C(t) = \beta e^{-\lambda t}\,,$$
$$\tau = \frac{1}{\lambda},$$

$$C'(t) = -\lambda \beta e^{-\lambda t}\,,$$

$$C''(t) = \lambda^2 \beta e^{-\lambda t}\,,$$

$$\frac{dC}{dt} = \left|e^{\beta} \lambda e^{\lambda t}\right|.$$

where β and λ are the linear regression intercept and slope, respectively, of the pairs of points $(t, \ln C)$. The intercept β can be calculated using the formula

$$\beta = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2}$$

and the slope can be calculated using the formula

$$\lambda = \bar{y} - \beta\bar{x}\ .$$

For example, the sample data has a β = −0.033623979 and λ = 1.39249071.

CHAPTER 3. UAFDUST CALCULATOR

3.1. UAFDUST Web Site

The Dust Palliative Mean Particle Residence Time Calculator, or just "UAFDUST", is a web application for automatically calculating the MPRT of a dustfall column test. A screen shot showing the application for a sample is shown in Figure 3-1. The calculator automatically processes the raw data in the form of a comma separated values (CSV) file format. In the figure, you will see a green plot of the original data, and a red line indicating the regression line. When the red line ends, the dust has reached a point where it is no longer decaying as it originally did at a time of 24 seconds.

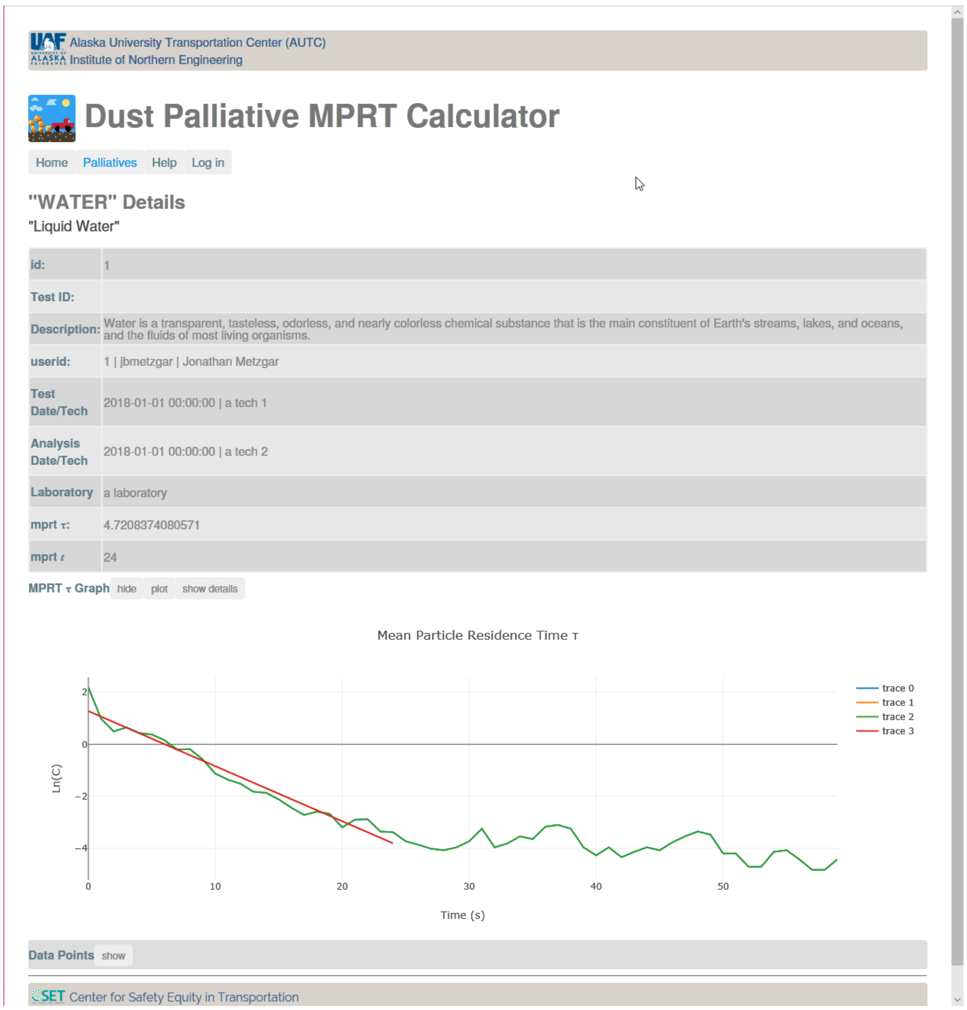

Figure 3-1. A Screen Shot of UAFDUST, the Dust Palliative MPRT Calculator.

3.2. User Interface Architecture

The user interface architecture of the application is shown in Figure 3-2. The application has three modes: initialization, home, and tech page. The initialization requires the user to accept a disclaimer regarding the data in the database. The home page allows the user to view help, search the stored palliatives, plot an MPRT, and print a report. The tech page allows a technician to add a new palliative, calculate an MPRT, and save a record to the database.

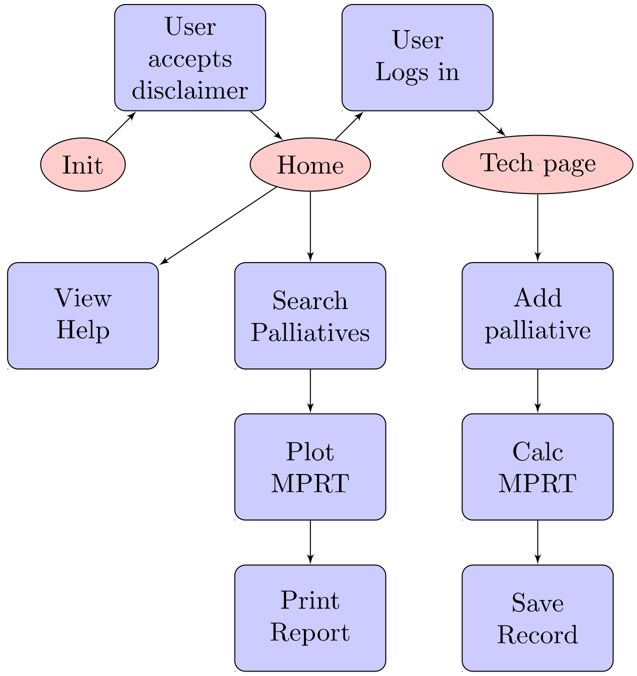

Figure 3-2. User interface architecture of the UAFDUST application.

3.3. Frontend and Backend Descriptions

The *frontend* of a website is the software that implements the experience for the end user. The *backend* of a website is the software that interacts with the database and performs tasks for administrative use. They can use very different kinds of *software stacks* which are targeted for working in a web browser (frontends) or a web server (backends). The software stack for the frontend of UAFDUST uses Angular.io and Plot.ly which are both JavaScript libraries. To improve the maintenance of the application, we use TypeScript, a language designed by Microsoft to add type checking to JavaScript which helps us avoid bugs caused by trying to use incompatible variable types. This is a commonly encountered error when using HTML and JavaScript.

The backend of the UAFDUST website uses PHP and SQLite 3. The benefit of using PHP is that we can create a web application that allows basic authentication and runs on nearly every web server. SQLite 3 is of benefit too because it is a standalone database which does not require a separate service to run on the backend. MySQL, Oracle, PostgreSQL, MSQL, and others often require an additional server to be configured. This may be of benefit if the application will serve many customers and can be easily added in future work. Figure 3-3 shows the administration page which allows users to be added and changed between admin and user roles. The *user* role corresponds to a technician on the frontend side of the app. Only *admin* roles have the ability to delete records from the database.

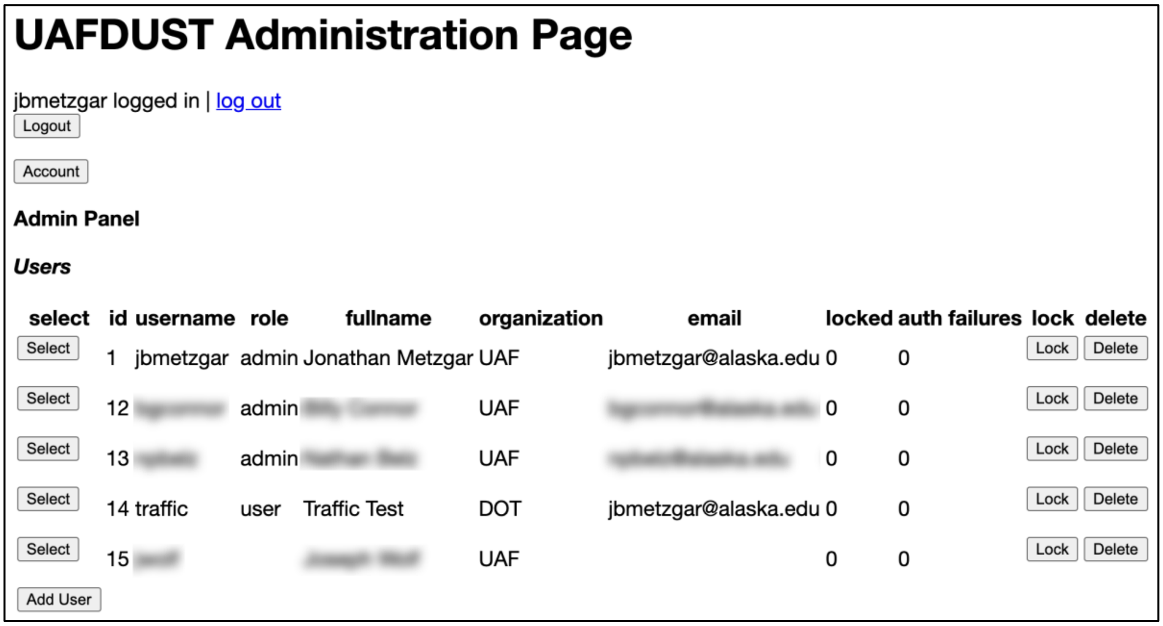

Figure 3-3. Screenshot of UAFDUST Administration Page.

3.4. Website and Source Code

The UAFDUST web application is served at the URL https://snow.ine.uaf.edu/~uafdust/. The source code for the application is currently hosted at https://github.com/uaf-cs/uaf-dust. The source code is written with TypeScript using the Angular.io and Plot.ly frameworks for the frontend. The backend uses a PHP and SQLite 3 database with some basic user authentication. The source code is licensed with the GNU Public License version 3.0.

CHAPTER 4. RESULTS AND DEVELOPMENT

4.1. Automated Workflow

One of the goals for the UAFDUST application was to change a manual process into an automated workflow. The previous method required a technician to utilize an Excel spreadsheet and apply the linear regression formulas and some custom formulas for the mean particle residence time (MPRT). Instead, the UAFDUST application can take the raw data from the DustTrak II sensor, in the form of a comma separated values (CSV) document, and have the software automatically perform all the calculations which eliminates any error from the technician.

Secondly, the old process did not have any requirements for the minimum amount of data needed to be stored with the MPRT data. So, we worked with the Alaska Department of Transportation to come up with a list of fields that should be included. For instance, we have fields for names of the technician and a certifying technician so that a final report can be generated. We also included a field for storing some metadata about the dust palliative itself.

We kept the number of data fields limited so that the database would promote completion of data which will help prevent sparsely populated fields. The fields we record include:

1. ID – the record primary key
2. Test ID – the laboratory proprietary test identification number
3. Description – a human readable description of what the dust palliative is
4. User ID – the user id who entered the form data
5. Test Date / Tech – the date and name of the technician who entered the form data
6. Analysis Date / Tech – the date and name of the certifying technician who is responsible for the verifying the calculation
7. Laboratory – the name of the laboratory that conducted the test
8. MPRT tau – the MPRT value of the dust palliative
9. MPRT t – the time after which the dust palliative stops being effective

4.2. Development

Primary development of the software was conducted by Dr. Jonathan Metzgar and Diane Murph. We utilized an Agile development methodology called Kanban to help prioritize the items into a *backlog*, which we could then focus on designing each of the components. For instance, earlier in the design process is more important for demonstrating key features. Then later we could focus on some of the important issues like user authentication which we would add to the application.

4.3. Improving UAFDUST

When the expert task group first met after reviewing the UAFDUST application, the main feedback was to include the ability to manage user logins which was not originally implemented. We designed a simple system using PHP to add user login sessions. The action required addition of the User ID field in the previous list. We were able to have normal users and administrative users. Normal users can add records while administrators can remove or modify records. Anonymous users, or users who are just visiting the website, can only view the records in read only mode.

4.4. Database Structure

Table 4-1. Database Structure of UAFDUST Application.

Table	Field	Type	Purpose
log	dtg	DATE	When the log message was recorded
	log	TEXT	The log message
palliatives	id	INTEGER	Primary key
	userid	INTEGER	User who created record
	testid	TEXT	Laboratory ID of test
	shortname	TEXT NOT NULL	Palliative short name (e.g. Water)
	longname	TEXT	Palliative long name (hydrogen …)
	laboratory	TEXT	Name of Laboratory
	testDate	TEXT	Date test occurred
	testTech	TEXT	Technician who conducted test
	analysisDate	TEXT	Date analysis occurred
	analysisTech	TEXT	Technician who analysed data
	description	TEXT	Human readable description of palliative
	data	TEXT	JSON array of data
	mprt	REAL	Tau
	mprtTime	REAL	Time in seconds
users	id	INTEGER	Primary key
	Username	TEXT	User name for login
	Password	TEXT	Hash of password
	Flags	TEXT	User role
	Firstname	TEXT	First name of user
	Lastname	TEXT	Last name of user
	Organization	TEXT	Organization of user
	Email	TEXT	Email of user

CHAPTER 5. CONCLUSION AND FUTURE WORK

This report details the UAFDUST application, or Dust Palliative Mean Particle Residence Time Calculator. It is a web application that allows laboratories in the state of Alaska to conduct MPRT calculations for tests using a dustfall column test. It eliminates a manual process of an Excel spreadsheet in favor of an automated system which can create, store, and retrieve previous dust palliative reports. It allows both a technician and a certifying official to record when the test was performed and validated.

In the future, we would like to see how different kinds of dust palliative tests could be compared with the current dustfall column test. Having an automated system perform the calculations could enable increased analysis of the effectiveness of dust palliatives and help the University of Alaska and the Alaska Department of Transportation select the best kinds of dust palliatives for use in rural transportation settings.

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[Accessed 10 04 2020].

APPENDIX A. SAMPLE DUSTFALL COLUMN DATA

run t (sec)	C
0	8.910
1	2.690
2	1.640
3	1.920
4	1.540
5	1.460
6	1.170
7	0.819
8	0.832
9	0.561
10	0.324
11	0.256
12	0.219
13	0.161
14	0.155
15	0.12
16	0.087
17	0.066
18	0.075
19	0.069
20	0.041
21	0.055
22	0.056
23	0.035
24	0.034
25	0.024
26	0.021
27	0.018
28	0.017
29	0.019
30	0.024
31	0.039
32	0.019
33	0.022
34	0.029
35	0.026
36	0.042
37	0.045
38	0.039
39	0.019
40	0.014
41	0.019
42	0.013
43	0.016
44	0.019

45	0.017
46	0.023
47	0.029
48	0.035
49	0.031
50	0.015
51	0.015
52	0.009
53	0.009
54	0.016
55	0.017
56	0.012
57	0.008
58	0.008
59	0.012

APPENDIX B. TECHNOLOGY TRANSFER PLAN

CSET UTC Technology Transfer Plan – YR2 Projects

Updated: January 20, 2021

In order to satisfy the new UTC Technology Transfer Plan (T2P) requirements, all projects funded under Year 2 must also provide a project-specific T2P containing the information listed below. The CSET T2P provides guidance for Principal Investigators both during and after the completion of CSET research projects on dissemination and sharing of research results and the development and potential adoption of each project's products. Please refer to the full CSET T2P for more information regarding the necessity and requirements of these plans.

ADHERENCE TO IMPLEMENTATION PLAN

The tasks and measures outlined in the CSET T2P identify research output, research outcomes, and research impact. We intend to contribute a completed product, report, and conference presentation, users' manual, and a student internship. At the time of this writing, we have already had a poster presentation, users' manual, and student internship.

NEED FOR RESEARCH PRODUCT

The UAFDUST product is necessary to continue the documentation, study, and dissemination of the effectiveness of dust palliatives which are used to manage dust on rural roads. The old method was a manual process and the UAFDUST application automates the analysis of dust palliative tests reducing errors and allowing dissemination of records for the Alaska Department of Transportation.

VALUE OF RESEARCH PRODUCT

The UAFDUST product is valuable to the University of Alaska and the Alaska Department of Transportation as it begins to catalog dust palliative MPRT measurements. This will enable data driven decisions of which palliatives are most effective given available choices.

IMPLEMENTATION TIMELINE

The development period is in 3rd quarter 2018 through 1st quarter 2019. The research product is scheduled for beta testing in first quarter 2019 with normal operation scheduled in second quarter 2019.

PROPOSED EXPERT TASK GROUP

- Billy Connor, UAF, 907-474-5552, bgconnor@alaska.edu
- Dr. David Barnes, UAF, 907-474-6126, dlbarnes@alaska.edu
- Dr. Nathan Belz, UAF, 907-474-5765, npbelz@alaska.edu
- Stephan Saboundjian, Alaska DOT, 907-269-6214, steve.saboundjian@alaska.gov

APPENDIX C. EXPERT TASK GROUP MEETING MINUTES

C.1. Meeting #1

August 7th, 2018

Attendees: Billy Connor, David Barnes, Stephan Saboundjian, Jonathan Metzgar

Synopsis

We demoed the prototype version of UAFDUST, the Dust Palliative Mean Particle Residence Time Calculator. We showed the capabilities of the online software including the following features:

- Add a palliative to the database
- Edit data points for the calculator
- Copy/paste raw data
- Calculate the mean particle residence time
- Plot charts of all the relevant calculations
- Save the palliative to the database
- View a list of palliatives
- Use browser print functionality to save a hardcopy report
- Showed the possibility for user authentication

We identified the following items as action items:

- Create the ability to login / out of the system
- Add admin panel to manage users
- Add warranty disclaimer to website before use
- Identify a permanent website for deployment
- Identify documentation for inclusion in app

If there are any questions about this meeting report, please contact me by email jbmetzgar@alaska.edu or phone (907) 474-6104.

Dr. Jonathan Metzgar
Assistant Professor
Department of Computer Science
College of Engineering and Mines
Duckering 543

C.2. Meeting #2

February 18th, 2019

Attendees: Billy Connor, Dr. David Barnes, Dr. Nathan Belz, and Stephan Saboundjian

Synopsis

We identified items for the technology transfer plan and a date for the final version of the website to be deployed.

APPENDIX D. USERS MANUAL

Welcome to the UAF Dust Palliative MPRT Calculator. It is designed to calculate the mean particle residence time, or Greek letter tau τ, of a dust palliative. This allows us to compare the performance of different palliatives using a scientifically based test which uses a nephelometer and dustfall column (shown in figures) to record the time and PM10 concentration for one minute. The purpose of this website is to enable technicians to upload test data, calculate the MPRT, and publish the results of such tests.

D.1. Finding out whether a palliative has been tested

Under palliatives, click on the palliative you would like to know more about. If it is not listed, it has not been tested yet.

D.2. Calculating palliative effectiveness

1. As a technician, you may log in to add a palliative to the database.
2. Go to the palliatives tab, type the name of the new palliative and click add.
3. Click on the newly created entry and add the details about the palliative you tested.
4. Submit the time in seconds and dust concentrations in the table or choose to import a CSV. Click submit. Your mean particle residence time will be calculated and graphed.

D.3. Admin

1. As an administrator, log in to manage database items.
2. To edit, add, or delete database items visit the Palliatives and Users pages. Little 'x' buttons will be added for deletion operations.